American Iron and Steel Institute

Green Engineering Case Study

Reducing Automobile Emissions and Saving Energy

ULSAB – Advanced Vehicle Concepts (ULSAB-AVC)

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Abstract

Figure 1 - ULSAB-AVC North American Midsize-Class Vehicle

The steel industry has developed complete conceptual designs for steel intensive compact and mid-size sedans. The designs specify gasoline and diesel powered models; in the U.S. combined driving cycle the mid-size sedan will achieve 52 miles per gallon (mpg) when equipped with a gasoline engine and 68 mpg when equipped with a diesel engine. This equates to only 0.32(diesel) – 0.38 (gasoline) lbs of CO_2 per mile (92 [diesel] – 108 [gasoline] grams per km). The automobiles are designed to be capable of achieving "Five-Star" crash safety rating based on the anticipated 2004 safety standards, and will cost no more to build than traditionally engineered mid-size sedans. By comparison, the 2000 fleet of mid-size automobiles in the USA averages 26.8 mpg (DoE Transportation Energy Data Book 2001 edition) and is not designed to meet the same stringent safety requirements as ULSAB-AVC.

The ULSAB-AVC utilizes advanced high-tech steels and modern manufacturing and engineering techniques that are available to automobile and auto parts manufacturers.

Background

Problem

In August of 2000, at a University of Michigan sponsored automotive management conference in Traverse City, Michigan, one of the principal speakers was the President and CEO of Toyota Motor Manufacturing Company of North America. In prepared remarks, he told his audience that the biggest challenge facing the automotive industry in the next decade would be to reduce the environmental footprint of the automobile.

The automotive industry to which he referred is global, and the makeup of the audience reflected that global reach. Within that global context it is clear, if one examines ambient air quality in the major cities of developing nations (e.g., Delhi, India or Shanghai, China[1]), that the human health effects deriving from increased personal transportation absolutely mandate the need to deal with the automobiles' "environmental footprint".

Lacking the same dramatic observable physical evidence but nonetheless with growing popular and governmental support, the same consciousness concerning the environmental footprint of the automobile is increasingly found in North America, Europe and the developed nations of the Pacific Rim.

In August of 2000, at the time of the conference, the environmentally focused, global steel industry ULSAB-AVC project, whose structure, goals and results follow, was approaching its second year.

However, it was widely perceived that the only way to accomplish this was by replacing steel, the standard material for automotive construction, with less dense materials. Unfortunately these materials have several disadvantages. First, they are <u>more</u> than three times the price of steel. Secondly, there are design, packaging, and safety considerations involved in substituting less dense materials for steel, and it is far from certain that the claimed weight saving can even be achieved. Lastly, these substitutes may impose increased environmental risks due to increased pollution during their manufacturing and the lack of an efficient and cost-effective recycling infrastructure. Steel, on the other hand, is 100% recyclable and is the engine that drives the vast majority of automobiles out of the waste stream and into the recycling stream. During the past decade,

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[1] Greenhouse Gas Scenarios for Delhi, India; Ranjan Bose - Tata Energy Research Institute and Daniel Sperling - Institute of Transportation Studies, University of California, Davis. Greenhouse Gas Scenarios for Shanghai, China; Hongchang Zhou – Tongi University, Shanghai and Daniel Sperling – Institute of Transportation Studies, University of California, Davis. Also PEW Center for Global Climate Change.

over 97% of the steel from end-of-life vehicles has been recycled here in North America.

Solution

To meet this challenge the ULSAB Consortium was formed. Initiated by the North American steel producers, the consortium is now composed of 33 steelmakers from around the world. Its task was to improve the structural efficiency of auto body structures and thereby their environmental performance, while at the same time maintaining their structural performance, safety, and affordability. This was to be accomplished by using innovative design along with the most advanced steels and manufacturing technique's available. It contracted with Porsche Engineering Services, Inc. (PES), who worked with the consortium to develop the project's goals and provided engineering and manufacturing management. Ultimately the ULSAB Project evolved into a series of projects that attacked the problems associated with the "body in white", closures, and suspension systems. Collectively these programs represent a $44 million investment by the world's steel producers in state-of-the-art automotive design. Appendix A contains a complete list of the ULSAB studies plus website addresses where detailed engineering reports can be obtained.

The culmination of the ULSAB program is the ULSAB–AVC (Advanced Vehicle Concepts). Starting with a blank sheet of paper and all that was learned from the earlier projects, the ULSAB-AVC project developed the conceptual design and engineering for two steel intensive, energy efficient, safe and affordable automobiles. Two complete vehicles were ultimately designed: a compact two-door hatchback and a mid-size four-door sedan. Both models are available in a diesel and gasoline powered versions. The design specification includes all performance characteristics and details the structural members, closures, and power train, as well as the seats, air conditioning and all other amenities normally found in mass-produced vehicles.

In addition, the ULSAB-AVC project performed Structural Performance Analysis, Crashworthiness Studies and developed a Manufacturing Cost Model. Appendix B contains a list of all of the ULSAB-AVC communiqués (Technical Transfer Dispatches) plus website addresses where detailed engineering reports can be obtained.

Goals of the ULSAB-AVC Project

The objectives of the project were first to establish performance benchmarks, set targets based upon those benchmarks and then provide conceptual designs that would meet or exceed those goals. The benchmarks were numerous but centered on the following:

- Crashworthiness for the anticipated 2004 requirements.
- Total vehicle mass.
- CO_2 emissions and fuel efficiency.
- Structural performance (bending and torsional rigidity and normal mode frequency).
- Affordability.
- Source reductions (reduced emissions thru manufacturing less steel).
- 100% recyclability.

Benchmark data was collected from numerous sources. In addition Porsche Engineering purchased and dismantled two mass-produced vehicles:

- Ford Focus, a popular design that meets current safety standards.
- Peugeot 206, an example of a 909 kg (2000 lb) vehicle, which provided good examples for a detailed component and mass benchmarks.

It was decided to provide the conceptual common platform design for two different vehicle sizes: Current production European C-class (Volkswagen Golf class) and US Department of Energy PNGV class (slightly larger than a DaimlerChrysler Cirrus). The vehicles would be designed using "holistic" principles. They would share a common platform and as many parts and structural members as possible. ULSAB-AVC was to provide complete automobile designs including body structure and closure panels, suspension, styling package, and all comfort and convenience accessories normally purchased as part of a mass-produced automobile. The designs would incorporate both gasoline and diesel engine variants, and would be designed to achieve a "Five Star" safety rating based on the anticipated 2004 safety standards for both United States and Europe.

European C- Class Vehicle

Two important program drivers for ULSAB-AVC were the U.S. Partnership for a New Generation of Vehicles (PNGV) and EUCAR (The European CO_2 reduction program) projects. These projects provided references for setting ULSAB-AVC targets. The focus of the EUCAR project is on a C-Class hatchback design similar to the VW Golf and Ford Focus. For this reason Porsche Engineering was asked to design one of the concepts to fit this type and size vehicle. While doing this ULSAB-AVC also addresses the most important class of vehicles in Europe and Japan.

PNGV– Class Vehicle

The Partnership for a New Generation of Vehicles (PNGV) program was established by the U.S. Department of Energy in 1994, some 14 months after the start of the original ULSAB project. PNGV's mission was to develop a five-passenger sedan comparable to the Ford Taurus and the competing Chrysler and General Motors' vehicles then popular. However, the PNGV vehicle was to be up to three times more fuel-efficient and have comparable purchasing price and operating (ownership) costs.

To achieve its mission, PNGV launched an aggressive program to develop a "super car". Two of the foremost design targets for PNGV were: (1) Reduce the weight of the vehicle 20-40% by substituting alternative materials for traditional steel construction and (2) replace the conventional internal combustion engine with a radically different primary power source, e.g. fuel cell or hybrid powertrain.

The ULSAB-AVC program adopted PNGV's challenge to design an affordable, fuel-efficient five-passenger sedan. However, the ULSAB-AVC "PNGV Class" is steel intensive. It uses advanced high-strength steels, advanced manufacturing techniques, innovative vehicle architecture but more modern, conventional engine technology.

Since the PNGV began, new more rigorous safety standard are being established for 2004. The ULSAB-AVC program anticipates and satisfies those future safety requirements.

Description of the Designs

The purpose of the ULSAB-AVC was to demonstrate the ability of steel to produce a structurally efficient, environmentally sound, safe, affordable automobile. Environmental benefits derive from efficient power and drive systems, structurally efficient, rigid structures and reduced overall vehicle mass.

The selection of steels for ULSAB-AVC required balancing structural strength, formability, crash energy management, joinability, and economy. Optimum balance was achieved through a simultaneous engineering process between Porsche Engineering Services and steel industry materials experts. The ultimate body structure is made completely of high-strength steel and uses over 80% advanced high-strength steel, with the majority of the components fabricated from dual phase steels. All components are manufactured either by stamping, roll forming, or hydroforming, Figure 2.

To provide a global solution, the ULSAB-AVC models are designed with a common body structure platform that utilizes 50% shared parts between the European C-Class and the North American PNGV Class vehicles. The common platform features are shown in figure 3. The PNGV vehicle has an extended wheelbase and structure to retain the size of the typical mid-size four-door sedan common in North America.

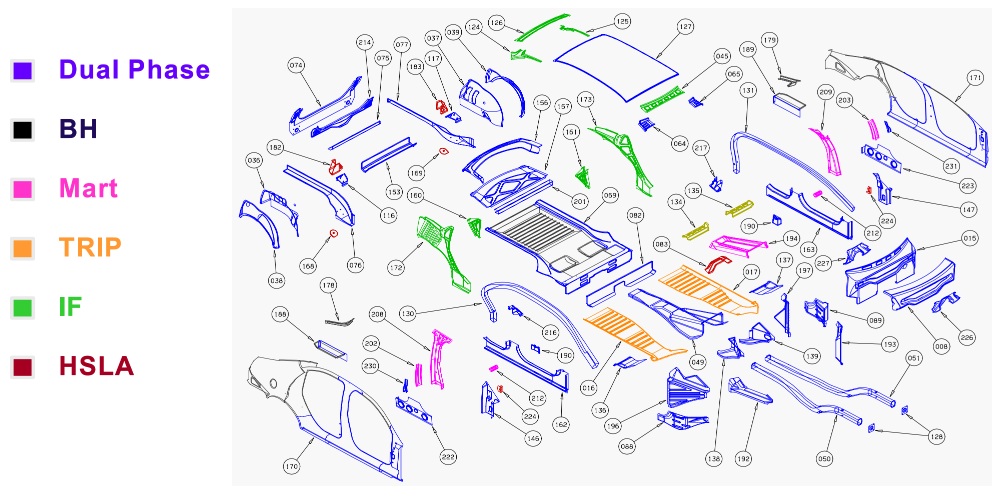

Figure 2 - ULSAB-AVC use of Advanced High Strength Steel

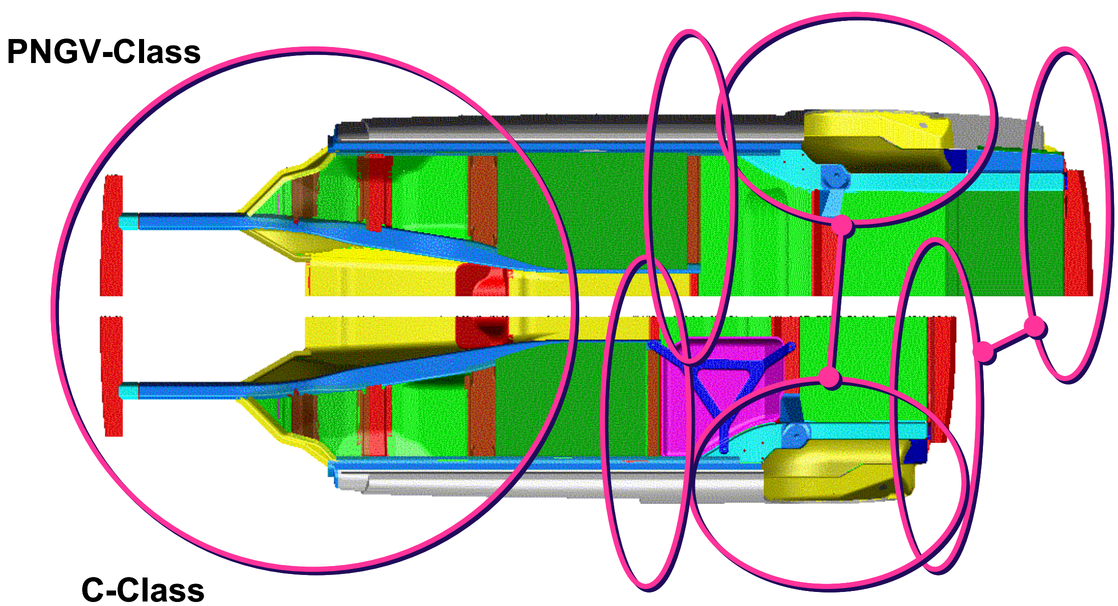

Figure 3 - ULSAB-AVC Common Platform Features

Prior to ULSAB-AVC, Porsche Engineering Services developed an extremely efficient body structure design in the first ULSAB project. In that project, Porsche employed a holistic design philosophy that treated the body structure as an integrated system rather than an assembly of parts. This approach created a more rigid and efficient structure by applying added strength at strategic locations and reducing weight elsewhere (essentially replacing fat with muscle).

For the ULSAB-AVC body-in-white Porsche also used the holistic design philosophy and developed unique body structures, the one for the PNGV-Class vehicle is shown on the left (figure 4). One hundred percent of the body structure employs high-strength (yield strength >210 Mpa) with over 80% advanced high-strength steel grades. Nearly 40% of the mass of the ULSAB-AVC body structure consists of parts using tailored blanks. Tailored blanking enables the engineer to design each part to an optimum shape and thickness such that maximum strength is obtained where needed and excess mass is eliminated.

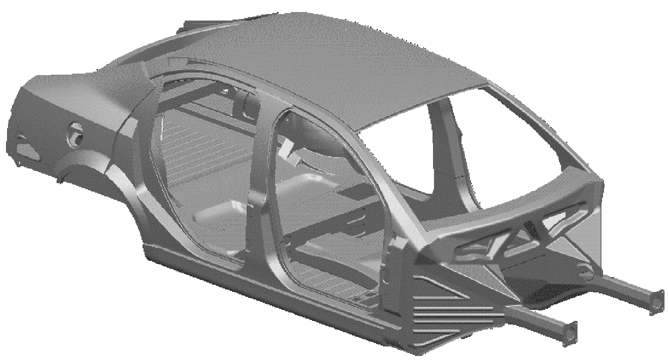

Figure 4 - ULSAB-AVC PNGV-Class Body Structure

Tubular hydroforming is employed in the structural members of both the body structure and inner door panels and sheet hydroforming for closure panels. The cold working effect produced by hydroforming increases the yield strength and dimensional stability of the steel parts.

Approximately 100 meters of laser welding is used assembling the ULSAB-AVC PNGV–Class body structure. Laser welding improves the static and dynamic strength of the joints and improves the aesthetic appearance at the joints. Because laser welding produces only a small heat affected zone, distortion and property changes are substantially reduced. Therefore, only about 800 spot welds, 1.6 meters of adhesive bonding, and less than one meter of MIG welding are required to construct the entire body structure.

The design techniques for the doors, hood, and trunk lid were developed in the earlier UltraLight Steel Auto Closures (ULSAC) project. It resulted in a lightweight frameless steel door design that achieves 42 percent weight savings over the average (benchmarked) frameless door, Figure 5.

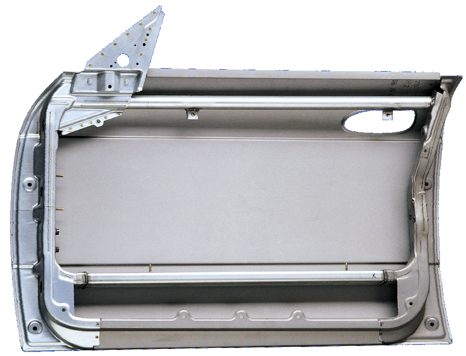

Figure 5 - Frameless Door Design

To achieve further mass reduction the ULSAC project developed a door outer panel using sheet hydroforming rather than stamping. Door structures were successfully manufactured with 0.6 mm Dual Phase (DP) 600 hydroformed steel outer panels. This door was 46% lighter than the averaged benchmarked door.

ULSAB-AVC is a front wheel drive vehicle. Its structurally efficient design and the stringent safety targets require a unique gearbox/engine layout. The engine is positioned behind the gearbox, allowing the powertrain to move rearward into the vehicles tunnel during a full frontal crash event without intruding into the passenger compartment. The engine position also contributes to lightweight design by significantly shortening the exhaust system.

The entire powertrain is located behind the front axle. This contributes to a 55/45-load distribution in ULSAB-AVC under normal conditions and even more evenly distributed axle loads under fully loaded conditions. This provides a load balance far superior to that found in typical front-wheel drive vehicles. This simplifies the suspension layout and in some designs may facilitate the elimination of stabilizer bars.

The cooling system, a radiator (gasoline engine models) and a radiator, plus intercooler (diesel engine model), is positioned on the suspension/engine/subframe in front of the gearbox and steering rack.

The fuel tank is positioned in a secure area in front of the rear suspension. The fuel tank capacity is 40 liters (10.6 gallons).

Both the gasoline and diesel engine concepts were selected from currently available state of the art engine technology based on: 1) the total vehicle target mass of the PNGV-class models and 2) the requirements for acceleration, cruising speed, and CO_2 emissions.

To achieve the performance specification and low emissions, a three cylinder VR3 engine with state-of-the-art power and torque characteristics was selected for both gasoline and diesel applications. The gasoline engine has an output of 61 kilowatts (82 HP) at 6000 rpm at a maximum torque of 108 Nm (80 ft. lbs.) at 4000 rpm. The mass of the gasoline engine is 83 kilograms. The turbocharged diesel engine has an output of 54 kilowatts (72 HP) at 4000 rpm at a maximum torque of 167 Nm (123 ft. lbs.) at 1800 rpm. The mass of the diesel engine is approximately 113 kilograms. The ULSAB-AVC designs can be adapted to incorporate future engine technologies, e.g. fuel cells and hybrid engines.

The gearbox selected for ULSAB-AVC features a 5-speed manual gearbox with an automatic shifter similar to the Volkswagen Lupo 3L (hydraulic) and the Opel Corsa (electric). With this gearbox, a computer selects the optimal shift points to achieve the best fuel consumption. The system also provides the driver with manual capabilities permitting the driver to select gears individually according to his or her driving style

CO_2 emissions were calculated based on the higher total vehicle mass of the PNGV-Class vehicle and the specified drive cycles. The analysis indicates that the target CO_2 <140 g/km will be achieved with both engine variants. The cruising range is 890 - 1140 km (550- 770 miles) on a single ten-gallon tank of gas.

Computer Aided Engineering -- Crashworthiness Studies

Crashes exert extreme loads on vehicles. Historically, designs have been based solely on steel's static properties. However, an important characteristic of steel is that its strength increases as the rate of deformation increases, as happens in a crash. Computer Aided Engineering (CAE) programs provide engineers with the ability to simulate crashes using dynamic material properties (see figure 6). This makes it possible to more accurately predict the response of a vehicle to impact loads and to optimize the design for safety.

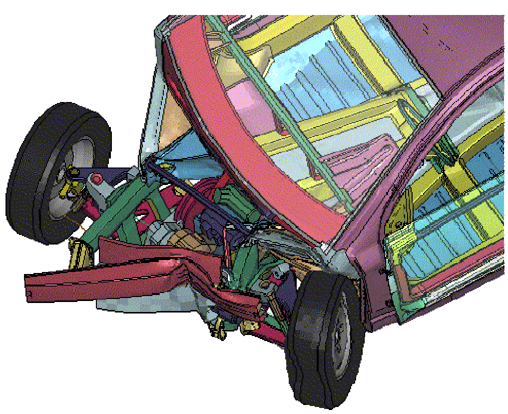

Figure 6 - CAE Crash Simulation

The objective of the CAE crashworthiness analyses was to check the safety of the various designs and to permit the optimization of the various structural components to provide maximum safety with the most structurally efficient design. The principal criteria for USAB-AVC is to design a vehicle that it is capable of achieving a U. S. Department of Transportation Five Star crash rating.

The crash events, which have been simulated in the design of ULSAB-AVC represent a mix of scenarios reflecting worldwide requirements:

- US-NCAP (35 mph, 56 km/h Frontal Impact).
- EuroNCAP (40% Offset Deformable Barrier 64 km/h, 40 mph Frontal Impact).
- SINCAP Side Impact (38.5 mph, 62 km/h Side Impact).
- Rear Impact (35 mph, 56 km/h Moving Barrier Rear Impact).
- Roof Crush/Rollover (Similar to US FMVSS 216 but using 2.5 times curb mass).

Consequently the crash simulations are, in general, significantly more severe than those used for current vehicles.

The crashworthiness analysis for the ULSAB-AVC program consisted of:

- Constructing the finite element (FE) models of the vehicle structure for the crash events.
- Analyzing the performance of a variety of structural design concepts using various design iterations, e.g. different steels, tailored blanks, etc.
- Using the results from the CAE analysis to optimize the design for crash and structural efficiency.
- Assessing the potential Star Ratings for US-NCAP, EuroNCAP and SINCAP through analysis of the crash simulations and by comparison to current vehicle body structure performance.

The CAE crash models have an estimated size of 200,000 elements and include representations of the:

- Body structure
- Engine and transmission
- Chassis system with subframe
- Steering column
- Radiator with fan
- Doors, front and rear (if applicable) without glass
- Wheels and tires
- Bumper system including crash box
- Fuel tank
- Fixed glass

Based on expert analyses of the simulations, all models of ULSAB-AVC were deemed to be capable of achieving Five Star ratings when compared with the results of existing highly rated vehicles. Calculations made on the PNGV type vehicle to assess front rail damage in a 15km/h (9mph) zero degree front impact showed that deformation remained within the bumper system.

(**Note:** The Star Rating system is a means of presenting the occupant injury results of the NCAP tests that can be easily understood by consumers. In the United States separate star ratings (up to five stars each for driver and passenger) are awarded to vehicles for the US-NCAP Full Frontal Impact test. Similarly, the SINCAP Side Impact test also has a five star rating system (again, 5 stars each for passenger and driver).

Manufacturing Cost Models

Porsche Engineering Services in collaboration with The Massachusetts Institute of Technology (MIT) developed a manufacturing cost model that includes all aspects of manufacturing: materials, labor, parts fabrication, assembly, and painting. It excludes manufacturing logistics and non-manufacturing overhead. The model was developed through interaction among product designers and engineers, assembly line designs, and used various cost assessment methods. To account for differences among manufacturers, the model allows a manufacturer to insert its figures into the various elements of the model. The manufacturing costs for the PNGV-Class vehicle range from $9,500 to $10,200.

Figure 7 compares the manufacturing costs of the two ULSAB-AVC models with the selling price of the various hybrid and PNGV-Class vehicles sold today. The selling price analysis incorporated information from manufacturer's data obtained through the Internet, automobile company literature and other sources in the public domain.

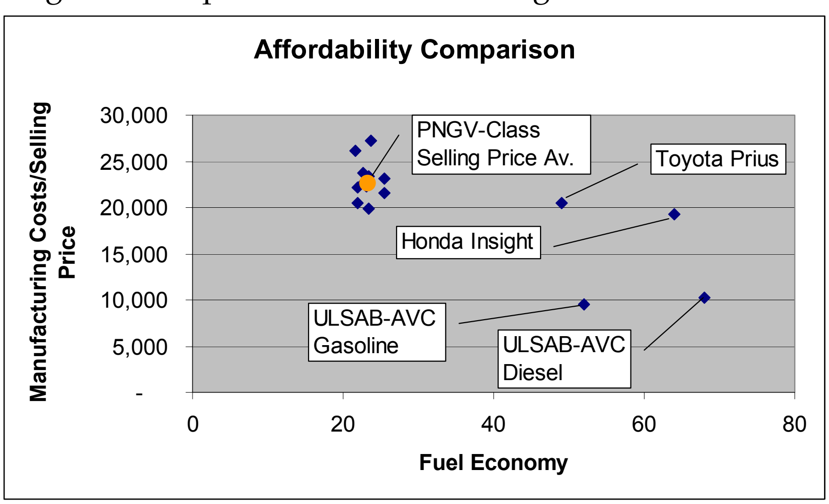

Figure 7 - Manufacturing Costs ULSAB-AVC vs. Selling Price for Competing Vehicles.

Figure 7 indicates that ULSAB-AVC vehicles have manufacturing costs far below the selling prices of hybrid and PNGV-Class vehicles. Their mileage is substantially better than current Midsize/PNGV-Class vehicles and comparable to that of the Toyota and Honda Hybrids.

Operating Costs

The Porsche Engineering Services model of vehicle performance developed the predicted mileage and CO_2 emissions for the ULSAB-AVC PNGV-Class vehicle. These are shown in Table 1 below. Assuming the price of gasoline is $1.25 per gallon and the owner drives 10,000 miles per year: the operator of typical vehicle achieving the C.A.F.E equivalent of 27.5 miles gallon, will spend $455/year on gasoline, while the owner of an ULSAB-AVC will spend only $240.

These assumptions significantly understate the consumers' true expenditures for gasoline. According to the Energy Information Agency, in 1999 the average U.S. vehicle achieved 21.4 miles/gallon, was driven 11,850 miles and consumed 552 gallons of gasoline. The typical SUV achieved only 17.1 miles/gallon, consumed 700 gallons and traveled 11,958 miles. (www.eia.doe.gov).

Energy and Environmental Benefits

The Porsche Engineering Services model of vehicle performance developed the predicted mileage and CO_2 emissions for the ULSAB-AVC PNGV-Class vehicle. Table 1 compares these with automobiles achieving the United States C.A.F.E. mileage standard. It shows that the gasoline driven ULSAB-AVC PNGV-Class vehicle almost doubles the C.A.F.E. standard and produces 47% less CO_2. The results of the diesel version are even more impressive.

	CAFE	ULSAB-AVC Gasoline	ULSAB-AVC Diesel
U.S. Combined [mpg]	27.5	52	68
CO_2 Emissions [g/km]	204	108	92

Table 1 - Comparison of Mileage and CO_2 Emissions.

Source Reduction

ULSAB-AVC's body structure is 45 kg or about 100 Lbs. lighter than the current benchmark average. Taken together with the accompanying engineered scrap this represents a source reduction opportunity of between 140 Lbs. and 150 Lbs. of steel per vehicle. Taken as an average mass reduction opportunity given the vehicle class involved, and extended across current North American production of all vehicles, it could mean over 1 million fewer tons of steel required to satisfy present market requirements. A substantial environmental achievement.

Recycling

As stated above, steel is 100% recyclable. Recyclability is the engine that drives end-of-life automobiles out of the waste stream and into the recycling stream, an efficient infrastructure consisting of over 12,000 dismantlers and the 300 shredders in North America. This scrap industry prepares end-of-life automobiles for recycling and allows the steel industry to recover virtually 100% of the steel content. Over 97% of end-of-life vehicles have been recycled over the past decade. Because steel scrap is a vital raw material, all steel products contain significant recycled content. Based on the composition of a typical family vehicle manufactured in North America in 2002, the average recycled content of the steel is 44%. It is also important to point out that over 30% is post-consumer scrap, and the remaining 14% comes from the manufacturing process.

Conclusion

If 1,000,000 ULSAB-AVC vehicles replaced an equivalent number of benchmark mid-size sedans, operating at the C.A.F.E. standard 27.5 miles per gallon, the annual savings that we would realize are estimated to be:

- Reduced fuel consumption: 171,330,000 gallons
- Cost savings at $1.25/gallon: $214,162,500
- Source reduction (less steel used): > 70,000 tons per yr.

Approximately 16 million new vehicles are produced in North America annually. Obviously, the above-cited environmental benefits that can be realized if ULSAB-AVC technology is applied universally are enormous.

Based on comprehensive cost modeling, all this would be accomplished at no cost penalty to the consumer.

Future work continues to incorporate the concepts and learnings from all the ULSAB- projects into Light Truck and Sport Utility Vehicles (more information on all ULSAB-projects can be found in the appendices).

A summary of the main results of ULSAB-AVC is shown in table 2.

Table 2: COMPARISON SUMMARY

	PNGV Class (reference)	ULSAB-AVC PNGV-Class	
	Gasoline	Diesel	Gasoline
Passengers	5/6	5/6	5/6
Curb Wt, kg	1470	1031	998
Body + Closures, kg	370	279	279
Engine			
Cylinders	4/6	3	3
Horsepower	131	72.4	81.8
Top Speed, Km/hr, Cont	205	184	194
Acceleration, 0-100km/hr	10.9	13.9	13.9
Fuel Type	regular	diesel	premium
Environmental			
Mileage, mpg	27.5	68	52
CO_2, g/km		89	108
Cost			
Production, $/unit		10,238	9,539
Gasoline, $/year			240

Appendix A:
ULSAB studies and website addresses:

UltraLight Steel Auto Body Final Report, Porsche Engineering Services, Inc. March 1998.

UltraLight Steel Auto Body Electronic Report, American Iron & Steel Institute, May, 1998

UltraLight Steel Auto Closures Final Report, Porsche Engineering Services, Inc. May 2001.

UltraLight Steel Auto Suspension Final Report, Lotus Engineering Services, Inc. January 2001.

www.ulsab.org

www.ulsac.org

www.ulsas.org

www.ulsab-avc.org

Appendix B:
ULSAB-AVC Technical Transfer Dispatches with website addresses:

Description of ULSAB-AVC Benchmarking and Target Setting Approach
http://www.ulsab-avc.org/ulsab_ttd.php3?section=0&chapter=1

Description of ULSAB-AVC CAE Analysis for Crashworthiness
http://www.ulsab-avc.org/ulsab_ttd.php3?section=0&chapter=2

Description of ULSAB-AVC Benchmarking and Target Setting
http://www.ulsab-avc.org/ulsab_ttd.php3?section=0&chapter=3

Description of ULSAB-AVC Styling
http://www.ulsab-avc.org/ulsab_ttd.php3?section=0&chapter=4

Preliminary Design Considerations for Packaging, Powertrain and Suspension
http://www.ulsab-avc.org/ulsab_ttd.php3?section=0&chapter=5

ULSAB-AVC Body Structure Materials
http://www.ulsab-avc.org/ulsab_ttd.php3?section=0&chapter=6